A Shifting Tide: Recommendations for Incorporating Science Communication into Graduate Training

Elizabeth J. Hundey, Jennifer H. Olker, Cátia Carreira, Rémi M. Daigle, Ashley K. Elgin, Michael Finiguerra, Natasha J. Gownaris, Nicole Hayes, Leanna Heffner, N. Roxanna Razavi, Patrick D. Shirey, Bradley B. Tolar, and Elisha M. Wood-Charlson

Abstract

Scientists who are skilled in communication reap professional and personal rewards. Unfortunately, gaps exist in fostering curricular and extracurricular training in science communication. We focus our article on opportunities for university- and department-level leadership to train new scientists to communicate effectively. Our motivation is threefold: (1) communication training is key to being competitive in the increasingly diverse job market, (2) training early career scientists in communication "jump-starts" personal and societal benefits, and (3) the authors represent a group of early career aquatic scientists with unique insights on the state of and need for training. We surveyed early career aquatic scientists about their science communication training experiences. In summary, survey respondents indicated that (1) science communication training is important; (2) graduate students are interested in training that is not currently available to them; (3) departments and advisors are moderately supportive of students participating in science communication, but less enthusiastic about providing training support; and (4) graduate students lack opportunities to put science communication training into practice. We recommend departments and institutions recognize the benefits of science communication training, develop a strategy to support such training, and facilitate individualized approaches to science communication.

Scientists, governments, funding agencies, professional societies, and policy makers agree that science communication is a critical component of science itself (Trench and Miller 2012). Yet, there is a growing recognition that we are not adequately training our scientists to communicate effectively (Brownwell et al. 2013).

So what exactly is science communication, why is it so important, and how do we train scientists to excel at it? Here, we adopt the definition of science communication developed by Burns et al. (2003, p. 183):" Science communication is defined as the use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science (the AEIOU vowel analogy): Awareness, Enjoyment, Interest, Opinion-forming, and Understanding."

Additional Supporting Information may be found in the online version of this article.

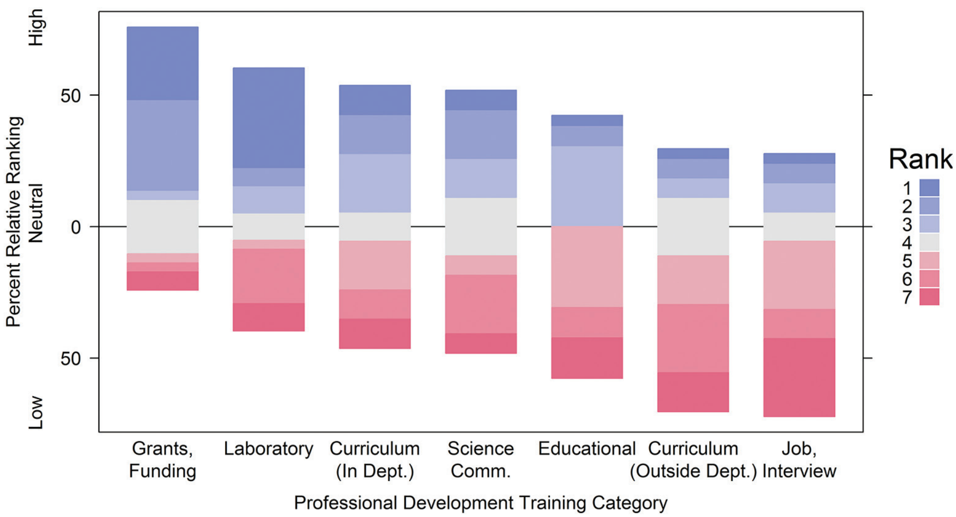

FIG. 1. The distribution of rankings of types of graduate training (SQ8). A ranking of 1 means an item is most important, while 7 is the least. Categories with more rankings in the Top 3 are skewed to the top half (in blue).

Burns et al. (2003, p. 184) also share that: "Science communication may involve science practitioners, mediators, and other members of the general public, either peer-to-peer or between groups."

As suggested by this definition, science communication practitioners, platforms, and goals are inherently diverse. Examples include publishing in peer-reviewed journals outside of one's speciality, conducting outreach activities at a local school, or sharing research findings with local media outlets. The benefits of enhanced science communication are vast:

- Practitioners reap both personal and professional rewards (Baron 2010), and often find enjoyment in outreach activities (Andrews et al. 2005)
- Researchers feel that sharing their expertise can fuel the passion for discovery in others, enhance science literacy, and improve public trust in the sciences (Pace et al. 2010).
- Scientists can access new research and funding opportunities, as well as a larger network of collaborators (Pace et al. 2010).
- Effective communication accelerates the discovery and implementation of solutions to pressing global issues (Lubchenco 1998), as the knowledge needed to address critical environmental, political, and social issues is often restricted to small subsets of the scientific community (Groffman et al. 2010).
- Society benefits (McGarvey and Mason 2015), and the public can have a more informed role in complex decision making (Kuehne et al. 2014).

Although there are many strategies for enhancing science communication, we focus on training new scientists during graduate school. Our motivation is threefold: (1) communication training is key to being competitive in the increasingly diverse job market, (2) training early career scientists in communication "jump-starts" personal and societal benefits, and (3) the authors represent a group of early career aquatic scientists from a range of graduate programs, and are thus able to provide unique insights on the state of and need for such training.

Our goal was to investigate perspectives on the need for and effectiveness of science communication training during graduate school. To this end, we administered an online survey (see Supporting Information) to a group of early career aquatic scientists about their science communication training experiences. We identified strengths and gaps in their experience and recommend how academic institutions can improve science communication training.

Survey

Driven by a demand for better science communication training, we surveyed early career aquatic scientists regarding the following: (1) what is the perceived importance of science communication training relative to other training activities? (2) what science communication activities are most important? and (3) what are the most prominent gaps in science communication training? The survey respondents consisted of scientists from the 2014 cohort of the Ecological Dissertations in the Aquatic Sciences (Eco-DAS) workshop, a program that aims to facilitate early career development and interdisciplinary collaborations for recent and pending Ph.D. graduates in the aquatic sciences. The survey questions (see Supporting Information) asked respondents to share their views of science communication training within the purview of their professional development and included both multiple choice and open-ended responses. The code used to analyze the survey data is open and archived in Daigle and Elgin (2016) and the data has been archived in Hundey et al. (2016).

Thirty Eco-DAS participants responded to the survey, an 85.7% response rate. Twelve of the authors participated in the 2014 Eco-DAS workshop and were among those invited to complete the survey. The respondents came from 20 different fields of study within the aquatic sciences, and studied in graduate laboratories with an average of 8.0 ± 6.3 trainees (undergraduates, graduates, and post-doctoral scholars). The respondents had a range of intended career trajectories (Supporting Information Fig. S1), with the majority considering multiple options. Academic research trajectories dominated the responses (19 respondents), but only three of these respondents listed this as their only potential career trajectory.

How Do Graduate Students Prioritize Science Communication Training?

When asked to rank the importance of different graduate training activities for professional development (Supporting Information: Survey Question (hereafter SQ) 8, SQ8), grant writing and obtaining funding stood out as the most important activities (Fig. 1). As one might expect for a graduate program in aquatic sciences, the second-highest ranked activity was training in laboratory skills. Science communication, which came in fourth, was viewed as being nearly equal in importance to departmental course offerings (third), which are currently a centerpiece of traditional graduate programs. Interestingly, science communication was ranked higher than training in education, a major component of a variety of science careers. Course offerings from other departments and job search/interviewing skills ranked lowest.

We asked respondents to rank the importance of different types of science communication activities and report how often they participated in these activities (SQ2-7,9). Science communication training and activities were divided into categories as presented in Supporting Information Fig. S2. Written (e.g., developing curriculum) and Oral (e.g., presentation at K-12 school) activities were clearly ranked as being the most important ways to communicate science (Fig. 2a), and it follows that these were the types of activities that respondents participated in the most (Fig. 2b). Social Media and Popular Media ranked lower in importance and also showed lower than average participation. In other areas, we found a mismatch between perceived importance and level of experience. For example, workshops were rated as having moderate importance, but higher than average participation. Conversely, the Visual Arts were ranked as being fairly important, but had the lowest level of participation.

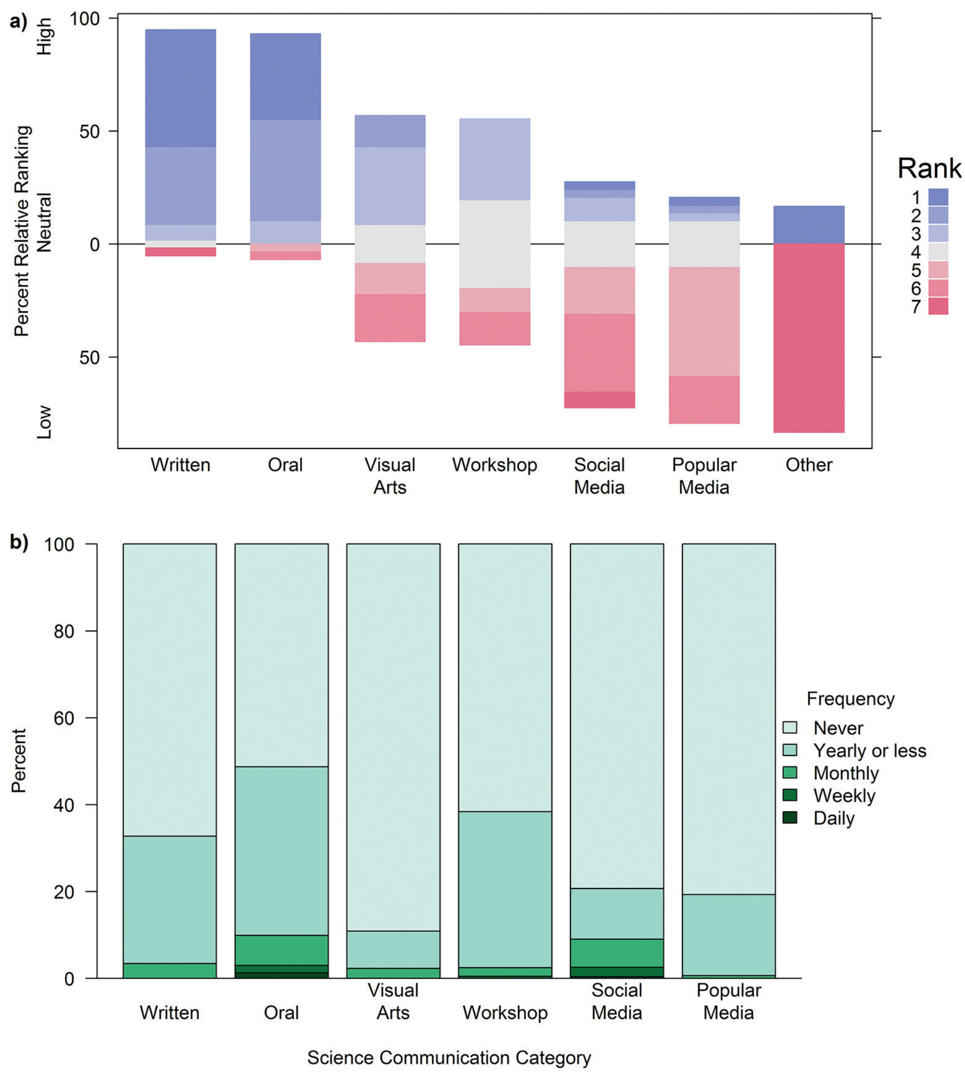

FIG. 2. (**a**) The distribution of rankings of types of science communication activities (SQ9). A ranking of 1 means an item is most important, while 7 is the least. Categories with more rankings in the Top 3 are skewed to the top half (in blue). (**b**) How frequently respondents participated in each communication category (SQ2-7), expressed as percent of total responses. See Fig. S2 for breakdowns of activities within each science communication category.

Strengths and Challenges in Science Communication Training

The source of training and number of training opportunities differed greatly among the science communication categories (Fig. 3). When asked why respondents did not participate in training for a particular activity, the dominant response across all categories was that training was not offered, even though participants were interested (mean = 77%, range: 59% for Social Media to ~ 85% for Interactive Workshops and Popular Media) (Table 1; SQ10,11). The greatest number of respondents reported receiving training in Oral and Written communication (Fig. 3). Overall, the most common sources of training were one's own university or self-guided methods. Self-guided training methods included resources such as books and online information, but also described by one participant as: "*… observing others who are great at* [science communication], *and hearing the stories of scientists who I admire and who are either involved in science communication or advocacy*." University training was dominant for Oral and Written Communication, while self-guided training was the most common method in the areas of Social Media and Visual Communication. Although training in Social Media was not common, its potential benefit was described by one respondent: "*Using this mode of communication, I've found papers that I would not have seen otherwise, given and received help with research or coding, met new colleagues in the 'Twitterverse' as well as disseminat*[ed] *my own research*."

A modest majority of survey respondents agreed that their advisors were supportive of them spending time on science communication activities (66% agreed or strongly agreed; SQ12-13, Supporting Information Table S1). However, advisors showing support by providing funding or direct training was less common (41% agreed or strongly agreed). A similar trend of more general approval than actual financial support was also reported at the departmental level (55% agreement for time spent, 45% agreement for funding or training provided). In general, advisors were viewed as more financially supportive than departments; 35% of respondents disagreed that their graduate program supported science communication activities by funding or providing training as compared to 21% of respondents in reference to their advisors.

When asked to expand upon the influence of advisor support for science communication, respondents most often described their advisors as neutral. While

TABLE 1. Level of interest and availability for types of science communication training when respondent did not participate (SQ11). See Supporting Information for survey questions.

	Not offered, not interested	Not offered, but interested	Offered, did not participate	*n*
Oral presentation	0%	78%	22%	9
Interactive workshop	12%	88%	0%	17
Popular media	13%	87%	0%	15
Written	0%	80%	20%	10
Visual	20%	73%	7%	15
Social media	35%	59%	6%	17
Overall	16%	77%	7%	n/a

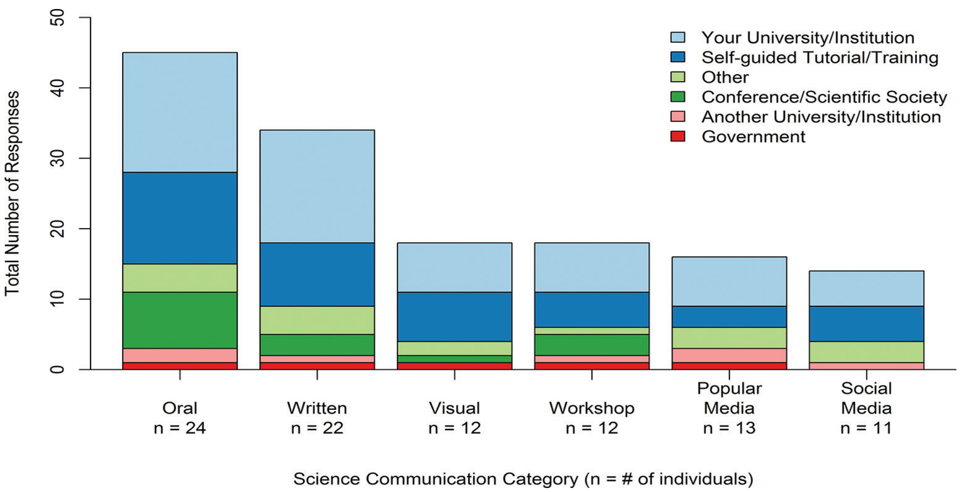

FIG. 3. Sources of training for each science communication type (SQ10). One respondent could give multiple answers (# of individuals responding indicated in category label). Bars with greater total heights indicate that more training opportunities were reported for that category.

one respondent noted that their supervisor believed in the importance of science communication and "led by example," a more common response was that advisors were supportive of science communication activities, but did not encourage those activities unless the student initiated it themselves. As one respondent explained: "*… science communication was (is) not part of their 'routine', and so for that it becomes secondary.*" Another respondent was more emphatic about faculty focus: "*Faculty are so grant and manuscript obsessed, they don't realize they are NOT preparing their students to effectively communicate outside their tiny research bubble.*"

Differing levels of support at the departmental level were also evident in respondents' open-ended answers. As one respondent noted, some faculty members were very supportive, but "*many other faculty discouraged or did not allow their students to participate because they didn't want them to 'get distracted' from their research.*" Some respondents felt that the low level of departmental support left them lacking something: "*Because there was no support for science communication I feel I am 'handicapped' in this regard. It is difficult for me to communicate in a simple way with the general public.*" Another individual noted: "*I think most of the training I received was quite good, but I have done relatively little science communication … the gap is in creating opportunities to communicate science.*'" In summary, students perceive that both students and faculty are concerned that the students may not be receiving adequate training, but they differ on their expectations of what that may be. The challenge to departments is to align the training they provide with the priorities identified by their graduate students, who will pursue a diversity of career paths.

Recommendations for Departments and Institutions

In summary, survey respondents indicated that (1) science communication training is important; (2) graduate students are interested in training that is not currently available to them; (3) departments and advisors are moderately supportive of students participating in science communication, but less enthusiastic about providing training support; and (4) graduate students lack opportunities to put science communication training into practice. The cry for more training among our respondents is widespread and at times passionate, as one respondent stated: "*…can we PLEASE just start institutionalizing this already?*"

We have compiled recommendations for institutions and departments based largely on the strengths and challenges identified by the survey respondents. These recommendations are to (I) recognize the full spectrum of benefits of science communication training; (II) develop a departmental strategy to support such training; and, (III) facilitate individualized approaches to science communication.

Recognize the benefit of training

Two of the primary measures of success in academia, funding success and publications, are becoming increasingly dependent on science communication. Most major granting bodies now require applicants to identify how their research will have a broader societal impact (e.g., U.S. National Science Foundation's Broader Impacts Criterion; Skrip 2015; Canada's PromoScience through NSERC: http://www.nserc-crsng.gc.ca/). Furthermore, 27% of scientific papers in the natural sciences go uncited within 5 yr of publication (Larivière et al. 2009), suggesting that many new publications could benefit from increased publicity. As the range of careers for science-trained graduates continues to expand, so does the need for effective communication skills. By mastering a new set of communication skills appropriate for diverse audiences, graduate students are better prepared for career opportunities in different sectors of the economy (McBride et al. 2011). Many of these careers are inherently based in science communication and require these skills outright (e.g., science writing for a news outlet, university, or federal research agency; Irion 2015; and coordinating communications for municipal and non-governmental organizations). But all science-related career paths benefit immensely from effective communication to diverse audiences (Pace et al. 2010; Fiske and Dupree 2014). Graduate students trained in K-12 outreach and education reported that the experience made them better teachers, but also better scientists (McBride et al. 2011). Science communication skills are important for all researchers, agency, private, or academic, for whom translation of results for management, policy, and public audiences is a necessity.

Graduate students are aware that changes in the job market also mean a broader set of skills are necessary to excel. Academic departments that recognize the demand for new skillsets and respond dynamically to these changes will be more appealing to students. For example, students' involvement in science communication can foster project management and leadership skills. For many graduate students, networks begin with their laboratory, department, and their advisor's collaborators. Involvement in science communication offers an opportunity to interact with scientists beyond discipline or geographic boundaries and engage with a range of stakeholders (Pace et al. 2010), including a diverse array of public audiences or policy makers. Expanding one's network has positive implications for job opportunities and collaborations. One survey respondent stated: "*Also, those communication skills are then applicable to so much more….professional communication to our peers, doing job interviews,* [and] *working collaboratively*." By engaging in dialogue with the public and other stakeholders, scientists can seek immediate and broad feedback on their work and ideas. Thus, the professional benefits associated with science communication and outreach continue later in academic careers (Pace et al. 2010), and may even have a positive effect on tenure and promotion (Jensen et al. 2008). These benefits may also propagate rapidly, as early career scientists engaged in science communication tend to target young demographics and the next generation of scientists (Messinger et al. 2009).

Academic units that embrace academic work beyond the peer-reviewed publication record will be leading the way in promoting and celebrating diverse departmental strengths. Scientific societies and publishers have recognized the growing role of science communication and are consequently diversifying their involvement in communication and engagement (e.g., Shugart and Racaniello 2015). For example, some online journal libraries and institutions use Altmetric (https://www.altmetric.com/), which tracks online activity of scholarly content such as mentions on Twitter, blog articles, and coverage by news outlets. Academic units can use this information in conjunction with baseline metrics of academic performance, given the strong correlation between wider dissemination activities and academic performance quantified by bibliometric records (e.g., Web of Science) (Jensen et al. 2008).

Embracing a greater role for science communication in a department can also increase department visibility. For example, communication platforms such as Twitter provide access to broader and more diverse audiences (e.g., Bik and Goldstein 2013) than those represented at scientific conferences (Bombaci et al. 2016). Sharing science via Twitter or other forms of social media may actually contribute to scholarly scientific impact (measured using h-index; Hirsch 2005) by raising awareness (Liang et al. 2014). Departments can enhance their visibility by ensuring that students are prepared for these moments and are favorable representatives of their academic unit. Audiences of a few individuals at a conference breakout session have social media networks that span hundreds of connections across the globe (Bombaci et al. 2016). One respondent encourages departments to take advantage of the marketing advantages of embracing science communication:

"*… I think departments can think selfishly about incorporating science communication into their programs. If their students are communicating their work, people will hear about your school and see the work of your department, which is a huge win from a PR* [Public Relations] *perspective*."

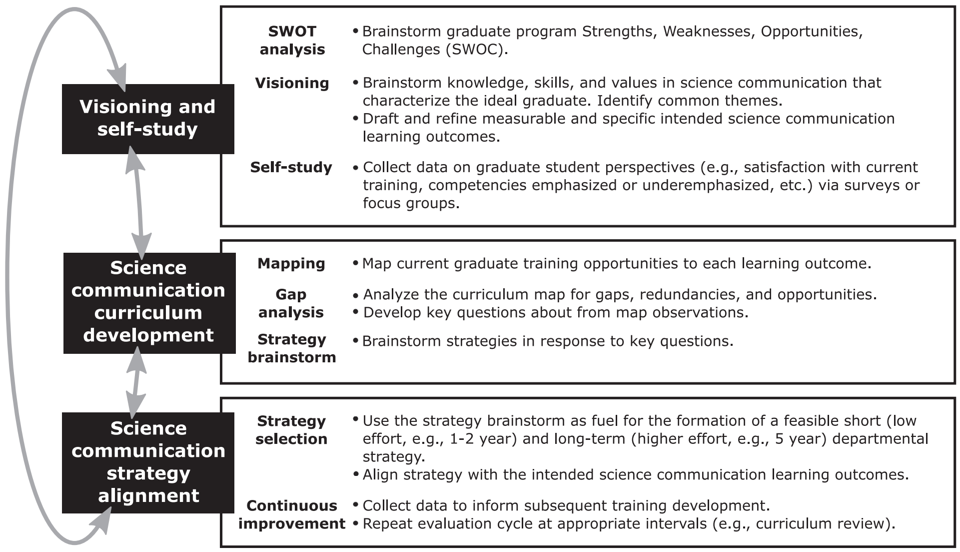

FIG. 4. Phases of science communication strategy development. Adapted with permission from Wolf (2007).

Develop a departmental strategy

Training graduate students and postdocs in science communication skills is not an onerous undertaking (Wood-Charlson et al. 2015), but these skills must be acknowledged as necessary and implemented as part of a strategic communication training plan in order to be effective. We recommend that departments develop their own tailored science communication strategy to maximize benefit to students and the department as a whole. Assessing current science communication offerings and developing a departmental strategy is, at its core, curriculum development (Gigante 2014), and should be driven by faculty members in consultation with students. Wolf (2007) outlines one curriculum approach that has been adapted here for developing a science communication strategy (Fig. 4).

The development of a tailored science communication training strategy could be achieved either during a curriculum review cycle, or independently as part of a continuous improvement process. Most institutions have support in the form of educational developers or curriculum specialists who can assist with the stages of this process (Stewart et al. 2015). Although a core group of faculty may champion the process of developing a science communication strategy, we recommend that all faculty be included in the visioning and brainstorming phases of strategy development.

Key stages in science communication development (e.g., Fig. 4) include mapping graduate curricula to intended learning outcomes and strategy brainstorming. The curriculum mapping process matches coursework to learning outcomes, and reveals gaps and strengths in current graduate curricula. The challenge for faculty members is to include individual, unstructured, or co-curricular graduate learning experiences (e.g., informal peer instruction, field work, and attending disciplinary conferences) in their evaluation of curricula and training.

Strategy brainstorming is intentionally open-ended; faculty members will come up with new ideas and may also leverage the expertise of individuals, programs, and institutions that regularly provide science communication training. Departments will likely brainstorm more strategies than are immediately feasible to implement, and therefore they will also be tasked with prioritizing their science communication strategies. Twenty survey respondents provided advice when asked for overall recommendations for graduate student training in science communication. We have incorporated these comments with our proposed strategies for departments.

Incorporate science communication into graduate program requirements

Several respondents indicated an interest in including science communication training within course requirements or electives. "*It should be built into required graduate coursework and students should be required to produce some sort of material that communicates their science to a public audience.*" Science communication courses may be a good fit within current curricula or within interdisciplinary enrichment programs in some cases.

Upon reflection, we caution against adding course and program completion requirements without consideration of trade-offs. Simply adding more milestones and requirements to a Ph.D. will not do students any favors without an honest assessment of current student workloads. Considering the average time from starting graduate school to the completion of a life sciences Ph.D. is 6.9 yr in the U.S.A. (National Science Foundation (NSF) 2009), any addition of science communication requirements will need to be balanced by removing or reducing other program requirements. For courses that involve science communication, we recommend that:

- Individual strategy development remains a central theme.
- Instructors adopt a facilitator rather than a lecturer role, as outlined in the social constructivist approach (Bauersfeld 1990). Here, students actively steer their own learning, construct knowledge collaboratively, and ensure that the value of the activities and assessments align with their own career goals.
- Students are encouraged to take a pragmatic approach and choose authentic activities and assessments that are practical outside of the course, align with their own science communication goals, and consider a range of audiences.

Provide authentic learning experiences and opportunities

One respondent recommended that graduate programs ought to provide "… *a hands-on course/program that requires students to take their work and their knowledge out into the world… to participate in real experiences and create real products*." This authentic learning is built upon the pragmatic assumption that students benefit from practice and assessment of intellectual tasks with real-world relevance (Wiggins 1990). If, for example, there is an expectation that scientists should be able to competently share their work with the public, then learning and assessment are built out of this challenge following the design elements of authentic learning (Reeves et al. 2002). An abundance of opportunities exist for collaborations and authentic experiences within or outside of the department. As one respondent stated:

> "*Grad programs could partner with other departments that are communications based, or work with other organizations, NGO's, etc, to create formal training and programmatic elements. Grad programs should also start implementing their own means of science communication (start a department blog, make and post videos, start a public lecture series) and then get the students directly involved.*"

Take advantage of existing opportunities and strengths

Seek out, evaluate, and raise awareness for existing opportunities within and outside of the institution, and provide support for those interested in participating. In cases where science communication sessions are incorporated into disciplinary conferences that students already frequent, the additional funding required may be minimal. For example, professional scientific societies such as the American Fisheries Society, the Association for the Sciences of Limnology & Oceanography, and the Ecological Society of America have hosted science communications workshops and symposia geared toward students and young professionals at their annual meetings. Identify students and faculty members who excel at science communication (e.g., blogging, speaking with the media, Twitter-experts), and start a conversation, a panel, a workshop, or a community of practice. Consider modifying existing departmental events rather than creating additional workload or expectations for attendance (e.g., swap out one or two departmental research talks each year for a workshop or panel).

Facilitate individual strategy development and approaches to science communication

We found that students are aware of their strengths and weaknesses and are best suited to identify the types of science communication training that would be most beneficial to them. This is clearly exemplified in the following responses to the question (SQ16): "How does your personality or individual strengths and weaknesses influence how you participate in certain science communication activities and training?"

> "*People should specialize in communication forums that are a good fit for them - every scientist does not need to be involved in every type of science communication.*"

> "*I have found several activities that I enjoy and seem effective (conducting workshops, created curricula, mentoring science fair students) - I believe that these activities work best*

> *for me because I enjoy working face-to-face with people and in small groups. I attempted blogging, but could not find the inspiration to create new content regularly."*

> *"I think I err towards more written (and organized oral presentation) forms of communication because I am introverted and nervous about speaking on the fly. That is why the media training is really critical… because it is what I'm most nervous about."*

Efficiency resonated as well: *"An individual scientist can only reach so many…but if you develop lesson plans that teachers can implement the impact is so much broader."* Similarly, strategy improves efficacy: *"I'm also one of those people who thinks something seems like a great idea, starts it, and then drops it (like I make blogs and then leave them to die on the internet) so I could clearly benefit from creating a real strategy for communication."*

Scientists communicate their work through a multitude of pathways which require different individual goals and skills. Therefore, departments may want to encourage graduate students to develop their own science communication strategy (e.g., a portfolio approach proposed by Kuehne et al. 2014). To foster this development, provide workshops, tools, and opportunities aimed at allowing students to: (1) highlight their strengths and improve on weaknesses; (2) identify where to best focus efforts based on goals and target audience; and (3) practice in authentic scenarios.

A Call for a Cultural Shift

First and foremost, we urge academic departments in the natural sciences to acknowledge that science communication is a worthy effort and an appropriate use of time and resources. The culture fostered by departmental leaders serves as an example to students. Departments benefit when administrators recognize faculty members that spend time on science communication: in practicing it themselves, raising awareness of program successes, and training students and peers.

In some cases, implementing this shift may require drastic changes in departmental culture, as one respondent noted: *"If you really want people to care you have to reduce the pressure to produce on papers. The students in my department were basically held to the standards of assistant professors in terms of productivity and service."* This reflects the possibility that priorities for student training may need re-evaluation in light of changing times and the increasing importance of non-traditional skills development.

Changing the department culture to enhance science communication training would impact the spread of information beyond the scientific community; gaining such skills allow scientists to better share ideas to the public and media, which improves scientific understanding and fosters curiosity.

> "For me, it is far better to grasp the Universe as it really is than to persist in delusion, however satisfying and reassuring." - Carl Sagan

Summary

Effective science communication accelerates discovery and implementation of solutions to global issues. In response to a survey, a group of early career scientists identified areas for departments and institutions to improve on science communication training:

I. Recognize the benefits of training as:
   1) it improves chances of obtaining funding;
   2) academic and non-academic careers depend on clear communication; and
   3) it provides wider visibility of institutions.

II. Develop a strategy to support training that:
   1) includes students and faculty in science communication curriculum development;
   2) provides and assesses authentic learning experiences;
   3) supports students taking advantage of existing internal and external training.

III. Facilitate individualized approaches to science communication by providing workshops, tools, and opportunities that will:
   1) highlight their strengths and improve on weaknesses;
   2) identify where to best focus efforts based on goals and target audience; and
   3) refine skills by communicating science in authentic scenarios.

Acknowledgments

Eco-DAS is jointly funded by the National Science Foundation and the Association for the Sciences of Limnology and Oceanography. The results and recommendations are based on the survey and input from a cross-disciplinary group of early career scientists that participated in Eco-DAS XI (Ecological Dissertations in the Aquatic Sciences) a symposium developed to provide training, support and opportunities to bridge inter-disciplinary gaps in aquatic ecology. Held in October 2014, Eco-DAS IX consisted of 35 recent and pending Ph.D. graduates in ecological oceanography and limnology, who came together to propose and write publications on important ecological issues that bridge participant expertise. This group represents professionals in Canada, U.S.A., Sweden, Australia, and Spain. This is NOAA Great Lakes Environmental Research Laboratory contribution 1834.

References

Andrews, E., A. Weaver, D. Hanley, J. Shamatha, and G. Melton. 2005. Scientists and public outreach: Participation, motivations, and impediments. J. Geosci. Educ. 53: 281–293. doi:10.5408/1089-9995-53.3.281

Baron, N. 2010. Stand up for science. Nature 468: 1032–1033. doi:10.1038/4681032a

Bauersfeld, H. 1990. The structuring of the structures: Development and function of mathematizing as a social practice, p. 137–158. *In* L. P. Steffe and J. Gale [eds.], Constructivism in education. Lawrence Erlbaum Associates Publishers.

Bik, H. M., and M. C. Goldstein. 2013. An introduction to social media for scientists. PLOS Biol. 11: e1001535. doi:10.1371/journal.pbio.1001535

Bombaci, S. P., C. Farr, T. Gallo, A. Mangan, L. Stinson, M. Kaushik, and L. Pejchar. 2016. Using Twitter to communicate conservation science from a professional conference. Conserv. Biol. 30: 216–225. doi:10.1111/cobi.12570

Brownell, S. E., J. V. Price, and L. Steinman. 2013. Science communication to the general public: Why we need to teach undergraduate and graduate students this skill as part of their formal scientific training. J. Undergrad. Neurosci. Educ. 12: E6–E10.

Burns, T. W., D. J. O'Connor, and S. M. Stocklmayer. 2003. Science communication: A contemporary definition. Public Underst. Sci. 12: 183–202. doi:10.1177/09636625030122004

Daigle, R., and A. K. Elgin. 2016. Analysis and figures for: "A shifting tide: Recommendations for incorporating science communication into graduate training." Figshare. Retrieved: 12 54, Sep 09, 2016 (GMT). Available from https://dx.doi.org/10.6084/m9.figshare.3814362.v1

Fiske, S. T., and C. Dupree. 2014. Gaining trust as well as respect in communicating to motivated audiences about science topics. Proc. Natl. Acad. Sci. USA 111: 13593–13597. doi:10.1073/pnas.1317505111

Gigante, M. E. 2014. Critical science literacy for science majors: Introducing future scientists to the communicative arts. Bull. Sci. Technol. Soc. 34: 77–86. doi:10.1177/0270467614556090

Groffman, P. M., C. Stylinski, M. C. Nisbet, C. Duarte, R. Jordan, A. Burgin, M. Andrea Previtali, and J. C. Cary. 2010. Restarting the conversation: Challenges at the interface between ecology and society. Front. Ecol. Environ. 8: 284–291. doi:10.1890/090160

Hirsch, J. E. 2005. An index to quantify an individual's scientific research output. Proc. Natl. Acad. Sci. USA 102: 16569–16572. doi:10.1073/pnas.0507655102

Hundey, E. J., and others. 2016. Data for: "A shifting tide: Recommendations for incorporating science communication into graduate training." Figshare. Retrieved: 12 55, Sep 09, 2016 (GMT). Available from https://dx.doi.org/10.6084/m9.figshare.3814383.v2

Irion, R. 2015. Science communication: A career where Phds can make a difference. Mol. Biol. Cell 26: 591–593. doi:10.1091/mbc.E14-03-0813

Jensen, P., J.-B. Rouquier, P. Kreimer, and Y. Croissant. 2008. Scientists who engage with society perform better academically. Sci. Public Policy 35: 527–541. doi:10.3152/030234208X329130

Kuehne, L. M., L. A. Twardochleb, K. J. Fritschie, M. C. Mims, D. J. Lawrence, P. P. Gibson, B. Stewart-Koster, and J. D. Olden. 2014. Practical science communication strategies for graduate students. Conserv. Biol. 28: 1225–1235. doi:10.1111/cobi.12305

Larivière, V., Y. Gingras, and É. Archambault. 2009. The decline in the concentration of citations, 1900–2007. J. Assoc. Inf. Sci. Technol. 60: 858–862. doi:10.1002/asi.21011

Liang, X., L. Yi-Fan Su, S. K. Yeo, D. A. Scheufele, D. E. Brossard, M. A. Xenos, P. Nealey, and E. A. Corley. 2014. Building buzz: (Scientists) communicating science in new media environments. J. Mass. Commun. Q. 91: 772–791. doi:10.1177/1077699014550092

Lubchenco, J. 1998. Entering the century of the environment: A new social contract for science. Science 279: 491–497. doi:10.1126/science.279.5350.491

McBride, B. B., C. A. Brewer, M. Bricker, and M. Machura. 2011. Training the next generation of renaissance scientists: The Gk-12 ecologists, educators, and schools program at the University of Montana. BioScience 61: 466–476. doi:10.1525/bio.2011.61.6.9

McGarvey, D. J., and C. A. Mason. 2015. Re-envisioning the communication of our science. Limnol. Oceanogr. Bull. 24: 1–4. doi:10.1002/lob.10007

Messinger, O., S. Schuette, J. Hodder, and A. Shanks. 2009. Bridging the gap: Spanning the distance between high school and college education. Front. Ecol. Environ. 7: 221–222. doi:10.1890/1540-9295-7.4.221

National Science Foundation (NSF). 2009. Doctorate Recipients from US Universities: Summary Report 2007-08. Division of Science Resources Statistics, Directorate for Social, Behavioral, and Economic Sciences, National Science Foundation.

Pace, M. L., and others. 2010. Communicating with the public: Opportunities and rewards for individual ecologists. Front. Ecol. Environ. 8: 292–298. doi:10.1890/090168

Reeves, T. C., J. Herrington, and R. Oliver. 2002. Authentic activities and online learning. Annual Conference Proceedings of Higher Education Research and Development Society of Australasia.

Shugart, E. C., and V. R. Racaniello. 2015. Scientists: Engage the public! mBio 6: e01989–01915. doi:10.1128/mBio.01989-15

Skrip, M. M. 2015. Crafting and evaluating broader impact activities: A theory-based guide for scientists. Front. Ecol. Environ. 13: 273–279. doi:10.1890/140209

Stewart, A. F., A. L. Williams, J. E. Lofgreen, L. J. Edgar, L. B. Hoch, and A. P. Dicks. 2015. Chemistry writing instruction and training: Implementing a comprehensive approach to improving student communication skills. J. Chem. Educ. 93: 86–92. doi:10.1021/acs.jchemed.5b00373

Trench, B., and S. Miller. 2012. Policies and practices in supporting scientists' public communication through training. Sci. Public Policy 39: 722–731. doi:10.1093/scipol/scs090

Wiggins, G. 1990. The Case for Authentic Assessment. ERIC Publications. Office of Educational Research and Improvement (ED). Report No. ED328611. Available from <http://pareonline.net/getvn.asp?v=2&n=2>

Wolf, P. 2007. A model for facilitating curriculum development in higher education: A faculty-driven, data-informed, and educational developer–supported approach. New Dir. Teach. Learn. 2007: 15–20. doi:10.1002/tl.294

Wood-Charlson, E. M., S. J. Bender, B. C. Bruno, J. M. Diaz, M. R. Gradoville, E. Loury, and D. A. Viviani. 2015. Translating science into stories. Limnol. Oceanogr. Bull. 24: 73–76. doi:10.1002/lob.10055

Elizabeth J. Hundey, Teaching Support Centre, The D.B. Weldon Library Rm 122. The University of Western Ontario, London, Ontario, Canada

Jennifer H. Olker, Natural Resources Research Institute, University of Minnesota Duluth, Duluth, Minnesota

Cátia Carreira, Department of Marine Microbiology and Biogeochemistry, Royal Netherlands Institute for Sea Research (NIOZ), Den Burg, The Netherlands

Rémi M. Daigle, Département de biologie, Université Laval, Québec, Québec, Canada

Ashley K. Elgin, National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan

Michael Finiguerra, Department of Ecology and Evolutionary Biology, University of Connecticut, Avery point Campus, Groton, Connecticut

Natasha J. Gownaris, Department of Biology, University of Washington, Seattle, Washington

Nicole Hayes, Department of Biology, University of Regina, Regina, Saskatchewan, Canada

Leanna Heffner, Western Alaska Landscape Conservation Cooperative, Anchorage, Alaska

N. Roxanna Razavi, Finger Lakes Institute, Hobart and William Smith Colleges, Geneva, New York

Patrick D. Shirey, Ecology Policy LLC, Sarver, Pennsylvania

Bradley B. Tolar, Department of Earth System Science, Stanford University, Stanford, California

Elisha M. Wood-Charlson, Center for Microbial Oceanography: Research and Education, University of Hawai'i at Mānoa, Honolulu, Hawaii